DRY CONVERTING PROCESS AND APPARATUS

Cross-Reference to Related Applications

[0001] This application is a continuation-in-part of and claims priority to U.S. Patent Application Serial No. 10/421,195, filed April 23, 2003, which in turn is a continuation-in-part of and claims priority to U.S. Patent Application No. 09/960,131, filed September 21, 2001 (now U.S. Patent No. 6,553,689 B2), which in turn claims priority to U.S. Provisional Application Serial Nos. 60/235,214, filed September 24, 2000, 60/235,221, filed September 24, 2000, and 60/274,050, filed March 7, 2001, all of which are hereby incorporated by reference in their entirety.

Field of the Invention

[0002] This invention relates to processes and equipment for converting moving substrates of indefinite length.

Background

[0003] Moving substrates of indefinite length (*viz.*, moving webs) can be converted in a variety of ways from one state or shape to another state or shape. Some converting processes produce considerable debris, or are carried out in the presence of airborne particulates or other contaminants, or may require a controlled environment when ordinary ambient air conditions might disrupt the converting process or pose a safety hazard. This can be a particular problem in dry converting operations, when static buildup may cause debris, particulates or other contaminants to adhere to the moving substrate. For example, optical-grade coatings on plastic films are especially sensitive to contamination, which may cause visible defects.

[0004] Typical controlled environments include clean rooms and the use of inert, low oxygen or saturated atmospheres. Clean rooms and special atmospheres require costly

auxiliary equipment and large volumes of filtered air or specialty gases. For example, a typical clean room operation may require many thousands of liters per minute of filtered air.

Summary of the Invention

[0005] The disclosed invention includes a process and apparatus for dry converting a moving substrate of indefinite length in a controlled environment using low volumes of filtered air or specialty gases. The disclosed process and apparatus utilize a close enclosure that envelopes the moving substrate during at least the converting operation, the close enclosure being supplied with one or more streams of conditioned gas flowing at a rate sufficient to reduce materially the close enclosure particle count. The invention thus provides in one aspect a process for dry converting a moving substrate of indefinite length comprising conveying the substrate through a dry converting station in a close enclosure while supplying the enclosure with one or more streams of conditioned gas flowing at a rate sufficient to reduce materially the particle count in the close enclosure.

[0006] The invention provides in another aspect an apparatus for converting a moving substrate of indefinite length comprising a dry converting station and substrate-handling equipment for conveying the substrate through the dry converting station, the substrate being enveloped in the dry converting station by a close enclosure supplied with one or more streams of conditioned gas flowing at a rate sufficient to reduce materially the particle count in the close enclosure.

[0007] The invention provides in yet another aspect a process for dry converting a moving substrate of indefinite length comprising conveying the substrate through a dry converting station in a close enclosure while supplying the enclosure with one or more streams of conditioned gas flowing at a rate sufficient to cause a material change in a physical property of interest for the atmosphere in the close enclosure.

[0008] The invention provides in yet another aspect an apparatus for converting a moving substrate of indefinite length comprising a dry converting station and substrate-handling equipment for conveying the substrate through the dry converting station, the substrate being enveloped in the dry converting station by a close enclosure supplied with one or more

streams of conditioned gas flowing at a rate sufficient to cause a material change in a physical property of interest for the atmosphere in the close enclosure.

Brief Description of the Drawing

[0009] The above, as well as other advantages of the disclosed invention will become readily apparent to those skilled in the art from the following detailed description when considered in light of the accompanying drawing in which:

[0010] **Fig. 1** is a schematic side sectional view of a disclosed slitting/cleaning apparatus.

[0011] **Fig. 2** is a schematic side sectional view of a disclosed laminating apparatus.

[0012] **Fig. 3** is a schematic side sectional view of a disclosed close enclosure.

[0013] **Fig. 4** is a perspective view of a disclosed distribution manifold.

[0014] **Fig. 5** is a partial schematic, partial cross sectional view of the distribution manifold of **Fig. 4** and associated conditioned gas supply and gas withdrawal components.

[0015] **Fig. 6** is a schematic cross sectional view of a transport roll and distribution manifold.

[0016] **Fig. 7** is a schematic side sectional view of another disclosed close enclosure.

[0017] **Fig. 8** is a schematic cross sectional view of the close enclosure of **Fig. 7**.

[0018] **Fig. 9** is a schematic side sectional view of another disclosed close enclosure.

[0019] **Fig. 10** is a schematic plan view of the overlying control surface in **Fig. 9**.

[0020] **Fig. 11** is a graph showing particle count versus pressure in a disclosed close enclosure.

[0021] **Fig. 12** is a graph showing oxygen level versus pressure in a disclosed close enclosure.

[0022] **Fig. 13** is a graph showing particle count versus pressure in a disclosed close enclosure.

[0023] **Fig. 14** is a graph showing pressures at various positions within a disclosed close enclosure.

[0024] **Fig. 15** is a graph showing pressure versus web slot height for a disclosed close enclosure.

[0025] **Fig. 16** is a graph showing particle count versus web slot height for a disclosed close enclosure.

[0026] **Fig. 17** is a graph showing particle count versus web speed at various pressures for a disclosed close enclosure.

[0027] Like reference symbols in the various figures indicate like elements. The elements in the drawing are not to scale.

Detailed Description

[0028] When used with respect to a flexible moving substrate or an apparatus conveying such substrates, the phrase "dry converting" refers to an operation carried out without applying or drying a wet coating on the substrate, wherein the operation changes the substrate's cleanliness state, surface energy, shape, thickness, crystallinity, elasticity or transparency. Dry converting may include, for example, operations such as cleaning (e.g., plasma treating or the use of tacky rolls), electrically priming (e.g., corona-treating), slitting, cutting into pieces, splitting (e.g., stripping into sheets), laminating, stretching (e.g., orienting), folding (e.g., corrugating), thermoforming, masking, demasking, vapor coating, heating or cooling.

[0029] When used with respect to an apparatus for converting a moving substrate or a component or station in such an apparatus, the phrase "dry converting station" refers to a device that carries out dry converting.

[0030] When used with respect to a moving substrate or an apparatus for converting such substrates, the words "downstream" and "upstream" refer respectively to the direction of substrate motion and its opposite direction.

[0031] When used with respect to an apparatus for converting a moving substrate or a component or station in such an apparatus, the words "leading" and "trailing" refer respectively to regions at which the substrate enters or exits the recited apparatus, component or station.

[0032] When used with respect to a moving substrate or an apparatus for converting such substrates, the word "width" refers to the length perpendicular to the direction of substrate motion and in the plane of the substrate.

[0033] When used with respect to an apparatus for converting a moving substrate or a component or station in such an apparatus, the phrase "web-handling equipment" refers to a device or devices that transport the substrate through the apparatus.

[0034] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the phrase "control surface" refers to a surface that is generally parallel to a major face of the substrate and located sufficiently close to the substrate so that an atmosphere that may affect the substrate is present between the control surface and the substrate. A control surface may include for example an enclosure housing, a separate plate, the walls of a slit, or other surface having an appreciable area generally parallel to a major face of the substrate.

[0035] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the word "overlying" refers to an apparatus, component or station that would be above the substrate if the substrate is envisioned in a horizontal orientation.

[0036] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the word "underlying" refers to an apparatus, component or station that would be below the substrate if the substrate is envisioned in a horizontal orientation.

[0037] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the word "headspace" refers to the distance from the substrate to an overlying nearby control surface measured perpendicular to the substrate if the substrate is envisioned in a horizontal orientation.

[0038] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the word "footspace" refers to the distance from the substrate to an underlying nearby control surface measured perpendicular to the substrate if the substrate is envisioned in a horizontal orientation.

[0039] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the phrase "close enclosure" refers to an enclosure whose average headspace plus average footspace throughout the enclosure is no greater than about 30 cm.

[0040] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the phrase "conditioned gas" refers to gas that is different from the ambient air surrounding the apparatus in at least one property of interest.

[0041] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the phrase "particle count" refers to the number of 0.5 μm or larger particles in a volume of 28.3 liters.

[0042] When used with respect to a physical property of interest (e.g., the particle count) for the atmosphere in an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the word "material" refers to at least a 50% reduction or increase in the property of interest compared to the ambient air surrounding the apparatus, component or station.

[0043] When used with respect to an enclosed apparatus for converting a moving substrate or an enclosed component or station in such an apparatus, the phrase "negative pressure" refers to pressure below that of the ambient air surrounding the apparatus, component or station, and the phrase "positive pressure" refers to a pressure above that of the ambient air surrounding the apparatus, component or station.

[0044] When used with respect to an apparatus for converting a moving substrate or a component or station in such an apparatus, the phrase "pressure gradient" refers to a pressure differential between an interior portion of the apparatus, component or station and that of the ambient air surrounding the apparatus, component or station.

[0045] A webline employing a slitter/cleaner in a close enclosure is shown in schematic side sectional view in **Fig. 1**. Unwind reel **12** supplies web **14** to slitter blades **16**. Unwind reel **12** may optionally be enclosed in a suitable cabinet may be unventilated, ventilated with ambient air, or supplied with a suitable conditioned gas stream as desired. Edge vacuums **18** remove contamination from the outer and slit edges of web **14**, and rubber rolls **20** and tacky rolls **22** remove contamination from the major faces of web **14**. Static eliminator bars **24** remove charge from web **14**. After passing over transfer rolls **27**, the slit portions of web **14** are individually wound on take-up reels **28** located inside cabinet **33**. Cabinet **33** typically does not benefit from employing a close enclosure, and instead desirably has a sufficiently

roomy and uncluttered interior to house the slit web rolls and permit easy roll changeover and transport. Cabinet **33** may be unventilated, ventilated with ambient air, or supplied with a suitable conditioned gas stream as desired.

[0046] The slitter/cleaner components are enveloped by a close enclosure **10** formed by overlying housing **30** and underlying housing **32**. Housings **30**, **32** may conform closely to the shape of the slitter/cleaner components to provide a reduced interior atmosphere and reduced interior volume. A further close enclosure and transition zone formed by overlying control surface **25** and underlying control surface **26** is interconnected to close enclosure **10** and is connected to cabinet **33**. Upper and lower manifolds **34** and **36** respectively may provide gas flows into or out of the apparatus (e.g., conditioned gas streams $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$) at a point downstream from the slitter/cleaner components. Conditioned gas streams $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ desirably differ from the ambient air by having a lower particle count, but may in addition or instead differ in another property of interest, e.g., a different chemical composition due to the absence or presence of one or more gases (including humidity) or a different temperature. Upper and lower manifolds **38** and **40** respectively may provide gas flows into or out of close enclosure **10** (e.g., withdrawn gas streams $\mathbf{M4_U}$ and $\mathbf{M4_L}$).

[0047] **Fig. 2** shows a schematic side sectional view of laminator **200**. Unwind reels **202** and transfer rolls **204** are located inside cabinet **205**. Cabinet **205** may be unventilated, ventilated with ambient air, or supplied with a suitable conditioned gas stream as desired. Webs **14** and **16** pass over transfer rolls **204**, between lamination rolls **206**, over transfer roll **208** and onto takeup roll **210** inside cabinet **211**. Cabinet **211** may be unventilated, ventilated with ambient air, or supplied with a suitable conditioned gas stream as desired. The lamination rolls **206** are enveloped by a close enclosure formed by overlying housing **212** and underlying housing **214**. This close enclosure is connected to cabinet **211**. Housings **212**, **214** may conform closely to the shape of the rolls **206** to provide a reduced interior atmosphere and reduced interior volume. A further close enclosure and transition zone formed by overlying control surface **215** and underlying control surface **216** is interconnected to the close enclosure formed by housings **212**, **214** and is connected to cabinet **211**. Upper manifolds **218**, **222** and lower manifolds **220**, **224** respectively may provide gas flows into or

out of the apparatus (e.g., conditioned gas streams $M1'_{U1}$, $M1'_{U2}$, $M1'_{L1}$ and $M1'_{L2}$). One or more of conditioned gas streams $M1'_{U1}$, $M1'_{U2}$, $M1'_{L1}$ and $M1'_{L2}$ desirably differ from the ambient air by having a lower particle count, but may in addition or instead differ in another property of interest, e.g., a different chemical composition due to the absence or presence of one or more gases (including humidity) or a different temperature.

[0048] The disclosed process and apparatus do not need to employ all the close enclosures shown in **Fig. 1** and **Fig. 2**, and may employ different close enclosures or processes than those shown or more close enclosures or processes than those shown. Two or more of the disclosed close enclosures may be interconnected in series in a web process thereby creating multiple successive zones or applications. Each individual close enclosure may be operated at different pressures, temperatures and headspace or footspace gaps to address process and material variants. Individual close enclosures may have none, one or more than one conditioned gas inputs or gas withdrawal devices. A positive pressure could be maintained or established in some close enclosures and a negative pressure in other close enclosures. For processes in which cleanliness is a concern, use of interconnected close enclosures is recommended from at least the first point at which debris or other contaminants may arise or pose a problem (e.g., after a slitter or before lamination rolls) up to at least a station at which debris or other contaminants may no longer pose a problem. Such interconnection can provide continuous protection that may reduce substrate contamination and facilitate control of the particle count in the atmosphere immediately surrounding the substrate while using only small volumes of conditioned gases. Additional control of converting conditions may be achieved by employing a close enclosure or series of interconnected close enclosures from at least the first dry converting station in a process, or from at least the first point at which debris or other contaminants may arise or pose a problem, up to or through at least the last dry converting station in a process (e.g., a cutting, slitting or folding station). Additional control may also be achieved by employing a close enclosure from the first dry converting station in a process (e.g., a cleaning or priming station) up to or through at least the last dry converting station in the process, up to a takeup reel or up to a packaging station. In one exemplary embodiment the coated substrate is not exposed to ambient air from at least the time the

substrate is unwound until it has been wound on a takeup reel or packaged. The disclosed apparatus may also include one or more sections that do not represent a close enclosure, but desirably the number, total volume and gas flow patterns of such sections is such that undesirable contamination of the substrate does not arise.

[0049] If desired, conditioned gas streams could be injected (or gas could be withdrawn) at more or fewer locations than are shown in **Fig. 1** and **Fig. 2**. In one exemplary embodiment, a conditioned gas stream could be injected at the first of several interconnected close enclosures, and the conditioned gas could be carried along with the moving substrate to the downstream close enclosures or pushed to an upstream enclosure or process. In another exemplary embodiment, conditioned gas streams could be injected wherever needed to maintain or establish a slight positive pressure in each of several interconnected close enclosures. In yet another exemplary embodiment, conditioned gas streams could be injected where needed to maintain or establish a slight positive pressure in some of several interconnected close enclosures, and a slight negative or zero pressure could be maintained or established in other interconnected close enclosures. In yet another exemplary embodiment, conditioned gas streams could be injected at each of several interconnected close enclosures.

[0050] A cleanroom could optionally surround the disclosed apparatus. However, this could be of a much lower classification and much smaller volume than that which might typically be used today. For example, the cleanroom could be a portable model using flexible hanging panel materials. Also, a variety of web support systems that will be familiar to those skilled in the art may be employed in the disclosed process and apparatus, including porous air tubes, air bars, and air foils.

[0051] In one embodiment of the disclosed process, a moving substrate of indefinite length has at least one major surface with an adjacent gas phase. The substrate is treated with an apparatus having a control surface in close proximity to a surface of the substrate to define a control gap between the substrate and the control surface. The control gap may be referred to as the headspace or footspace between the substrate and the nearby control surface.

[0052] A first chamber may be positioned near a control surface, with the first chamber having a gas introduction device. A second chamber may be positioned near a control surface, the second chamber having a gas withdrawal device. The control surface and the

chambers together define a region wherein the adjacent gas phases possess an amount of mass. At least a portion of the mass from the adjacent gas phases is transported through the gas withdrawal device by inducing a flow through the region. The mass flow can be segmented into the following components:

M1 means total net time-average mass flow per unit of substrate width into or out of the region resulting from pressure gradients,

M1' means the total net time-average mass flow of a gas per unit width into the region through the first chamber from the gas introduction device,

M2 means the time-average mass flow of conditioned gas per unit width from or into the at least one major surface of the substrate into or from the region,

M3 means total net time-average mass flow per unit width into the region resulting from motion of the material, and

M4 means time-average rate of mass transport through the gas withdrawal device per unit width, where

"time-average mass flow" is represented by the equation $MI = \frac{1}{t}\int_0^t mi\,dt$, wherein MI is the time-average mass flow in kg/second, t is time in seconds, and mi is the instantaneous mass flow in kg/second.

The mass flow in the gas phase is represented by the equation:

$$\mathbf{M1 + M1' + M2 + M3 = M4} \qquad \text{(Equation A).}$$

[0053] **M1, M1', M2, M3** and **M4** are further illustrated in **Fig. 3**. **Fig. 3** is a schematic side sectional view of a close enclosure **300**. A substrate **312** has at least one major surface **314** with an adjacent gas phase (not shown in **Fig. 3**). The substrate **312** is in motion in the direction of arrow "**V**" under a control surface **315**, thus defining a control gap "$\mathbf{G_C}$". A first chamber **317** having a gas introduction device **318** is positioned near the control surface **315**. The exact form of the gas introduction device **318** may vary, and expedients such as a gas knife, a gas curtain, or a gas manifold can be used. While the illustrated embodiment depicts first chamber **317** in the form of a plenum, it is not necessary that the gas introduction device **318** be positioned at a remove from the level of control surface **315**. A second chamber **319** is also positioned near the control surface **315**, and has a gas withdrawal device **320**. Once

again, while the illustrated embodiment depicts the second chamber **319** in the form of a plenum, it is not necessary that the gas withdrawal device **320** be positioned at the level of control surface **315**. In an exemplary embodiment, the first chamber **317** and the second chamber **319** will be at opposing ends of the control surface **315** as depicted in **Fig. 3**. The first chamber **317** defines a first gap **G1** between the first chamber **317** and the substrate **312**. The second chamber **319** defines a second gap **G2** between the second chamber **319** and the substrate **312**. In some embodiments, the first gap **G1**, the second gap **G2**, and the control gap G_C are all of equal height, however in other embodiments, at least one of the first gap **G1** or the second gap **G2** has a height different than the control gap G_C. Best results appear to be achieved when the first gap, second gap and control gap are all 10 cm or less. In some exemplary embodiments the first gap, the second gap, and the control gap are all 5 cm or less, 3 cm or less, or even smaller values, e.g., 2 cm or less, 1.5 cm or less, or 0.75 cm or less. The airflow required to attain a desired low particle count may vary in part with the square of the combined headspace and footspace, and accordingly the disclosed gaps desirably have relatively small values. Similarly, best results appear to be achieved when the total of the average headspace and average footspace is 10 cm or less, 5 cm or less, 3 cm or less, or even smaller values, e.g., 2 cm or less, 1.5 cm or less, or 0.75 cm or less.

[0054] In addition to gaps G_C, **G1** and **G2**, control of the atmosphere near the substrate may also be aided by using mechanical features, such as extensions **323** and **325** in **Fig. 3**. The extensions **323** and **325**, having gaps **G3** and **G4**, may be added to one of both of the upstream or downstream ends of the apparatus. Those skilled in the art will recognize that the extensions may be affixed to various members of the apparatus or provided with alternate shapes depending on the specific embodiment selected for a particular purpose. Flows **M1** and **M3** may be reduced as the substrate area "covered" by the extensions increases. The adjacent gas phase between the control surface **315**, first chamber **317**, second chamber **319** and the surface **314** of the substrate **312** define a region possessing an amount of mass. The extensions **323** and **325** may further define the region under the control surface having an adjacent gas phase possessing an amount of mass. The mass in the region is generally in a gas

phase. However, those skilled in the art will recognize that the region may also contain mass that is in either the liquid or solid phase, or combinations of all three phases.

[0055] **Fig. 3** depicts the various flow streams encountered in close enclosure **300** when practicing the disclosed process. **M1** is the total net time-average mass flow per unit width into or out of the region resulting from pressure gradients. **M1** is a signed number, negative when it represents a small outflow from the region as the drawing depicts, and positive when it represents a small inflow into the region, opposing the depicted arrows. Positive values of **M1** essentially represent a dilution stream and possible source of contaminants that desirably are reduced and more desirably are made negative for the overall portion of the apparatus constituting interconnected close enclosures. **M1'** is the total net time-average mass flow of conditioned gas per unit width into the region from gas introduction device **318**. If brought to a sufficient level, **M1'** reduces the particle count in the close enclosure. Excessively high **M1'** flows desirably are avoided in order to limit disturbance of substrate **312**. **M2** is the time-average mass flow per unit width from or into at least one major surface of the substrate into the region and through the chamber. **M2** essentially represents evolution of volatile species or other material from substrate **312** into close enclosure **300**. **M3** is the total net time-average mass flow per unit width into the region and through the chamber resulting from motion of the substrate. **M3** essentially represents gas swept along with the substrate in its motion. **M4** is the time-average rate of mass transported per unit width through the gas withdrawal device **320**. **M4** represents the sum of **M1** + **M1'** + **M2** + **M3**.

[0056] Mass flow through a close enclosure may be assisted by employing a suitable seal with respect to the moving substrate (*viz.*, a "moving substrate seal") at an upstream or downstream inlet or outlet of a close enclosure or connected chain of close enclosures. The seal may function as a sweep to prevent gas from entering or exiting the close enclosures. The seal could also include for example a forced gas, mechanical or retractable mechanical seal such as those shown in U.S. Patent No. 6,553,689, or a pair of opposed nip rolls. A retractable mechanical sealing mechanism can allow passage of splices and other upset conditions. It may be desirable briefly to increase one or more nearby conditioned gas flow rates (or to decrease or switch one or more nearby gas withdrawal rates) to maintain the

desired atmosphere near the seal. A pair of opposed nip rolls may be located for example, upstream or downs stream from the first or last dry converting station in a process.

[0057] By using a control surface in close proximity to the substrate surface, a supply of conditioned gas and a positive or small negative pressure gradient, a material particle count reduction may be obtained within a close enclosure. The pressure gradient, **Δp**, is defined as the difference between the pressure at the chamber's lower periphery, **pc**, and the pressure outside the chamber, **po**, wherein **Δp=pc-po**. Through appropriate use of conditioned gas and adjustment of the pressure gradient, particle count reductions of, for example, 50% or more, 75% or more, 90% or more or even 99% or more may be achieved. An exemplary pressure gradient is at least about -0.5 Pa or higher (*viz.*, a more positive value). Another exemplary pressure gradient is a positive pressure gradient. As a general guide, greater pressures can be tolerated at higher moving substrate speeds. Greater pressures can also be tolerated when moving substrate seals are employed at the upstream and downstream ends of a series of interconnected close enclosures. Those skilled in the art will appreciate that the close enclosure pressure(s) may be adjusted based on these and other factors to provide a desirably low particle count within appropriate portions of the disclosed apparatus while avoiding undue substrate disturbance.

[0058] The disclosed process and apparatus may also substantially reduce the dilution gas flow, **M1**, transported through the chamber. The disclosed process and apparatus may, for example, limit **M1** to an absolute value not greater than 0.25 kg/second/meter. **M1** may be, for example, less than zero (in other words, representative of net outflow from the close enclosure) and greater than -0.25 kg/second/meter. In another exemplary embodiment, **M1** may be less than zero and greater than -0.1 kg/second/meter. As is shown in the examples below, small negative enclosure pressures (which may correspond to slight positive **M1** flows) can be tolerated. However, large negative enclosure pressures (which may correspond to large positive **M1** flows) may cause adverse effects including dilution of mass in the adjacent gas phase, introduction of particles and other airborne contaminants, and introduction of uncontrolled ingredients, temperatures or humidity.

[0059] In one exemplary embodiment we control a process by appropriately controlling **M1'** and **M4**. A deliberate influx of a conditioned gas stream (e.g., a clean, inert gas having a

controlled humidity) can materially promote a clean, controlled atmosphere in the close enclosure without unduly increasing dilution. By carefully controlling the volume and conditions under which **M1'** is introduced and **M4** is withdrawn (and for example by maintaining a slight positive pressure in the close enclosure), flow **M1** can be significantly curtailed and the close enclosure particle count can be significantly reduced. Additionally, the **M1'** stream may contain reactive or other components or optionally at least some components recycled from **M4**.

[0060] The headspace or footspace may be substantially uniform from the upstream end to the downstream end and across the width of the close enclosure. The headspace or footspace may also be varied or non-uniform for specific applications. The close enclosure may have a width wider than the substrate and desirably will have closed sides that further reduce time-average mass flow per unit width from pressure gradients (**M1**). The close enclosure can also be designed to conform to different geometry material surfaces. For example, the close enclosure can have a radiused periphery to conform to the surface of a cylinder.

[0061] The close enclosure may also include one or more mechanisms to control the phase of the mass transported through the close enclosure thereby controlling phase change of the components in the mass. For example, conventional temperature control devices may be incorporated into the close enclosure to prevent condensate from forming on the internal portions of the close enclosure. Non-limiting examples of suitable temperature control devices include heating coils, electrical heaters, external heat sources and heat transfer fluids.

[0062] Optionally, depending upon the composition of the gas phase composition, the withdrawn gas stream (**M4**) may be vented or filtered and vented after exiting the close enclosure. The gas phase composition may flow from one or more of the close enclosures to a subsequent processing location, e.g., without dilution. The subsequent processing may include such optional steps as, for example, separation or destruction of one or more components in the gas phase. The collected vapor stream may contain particulate matter which can be filtered prior to the separation process. Separation processing may also occur internally within the close enclosure in a controlled manner. Suitable separation or destruction processes will be familiar to those skilled in the art.

[0063] It is desirable to avoid airflow patterns that might unduly disturb the substrate. **Fig. 4** is a perspective view of a disclosed distribution manifold **400** that can assist in providing an even flow of supplied conditioned gas (**M1'**). Manifold **400** has a housing **402**, and mounting flanges **404** flanking slit **406**. Further details regarding manifold **400** are shown in **Fig. 5**, which is a schematic partial cross sectional view of manifold **400** and an associated gas conditioning system. Gas source **502** supplies a suitable gas (e.g., nitrogen or an inert gas) to gas conditioning system **508** via line **504** and valve **506**. System **508** is optionally supplied with additional reactive species via lines **510**, **512** and **514** and valves **511**, **513** and **515**. System **508** supplies the desired conditioned gas stream to manifold **400** via line **520**, valve **516** and flow sensor **518**. Vacuum line **522** may be used to withdraw gas from manifold **400** via flow sensor **524**, valve **526** and vacuum pump **528**. The presence of both a supply line and a vacuum line enables manifold **400** to be used as a conditioned gas introduction or gas withdrawal device. Gases entering manifold **400** pass through head space **520**, around diverter plate **532**, and through distribution media **534** (made, e.g., using white SCOTCHBRITE™ nonwoven fabric, commercially available from 3M Co.), and then pass through a first perforated plate **536**, HEPA filter media **538** and a second perforated plate **540** before entering slit **406**. Gasket **542** helps maintain a seal between flanges **404** and perforated plate **540**. Manifold **400** can help supply a substantially uniform flow of supplied conditioned gas across the width of a close enclosure. The pressure drop laterally in the head space **520** is negligible in comparison to the pressure drop through the remaining components of manifold **400**. Those skilled in the art will appreciate that the dimensions or shape of head space **520** and the pore size of distribution media **534** may be adjusted as needed to vary the flow rate across the length of distribution manifold **400** and along the width of a close enclosure. The flow rate along the length of distribution manifold **400** can also be adjusted by using an array of bolts or other suitable devices arranged to bear against diverter plate **532** and compress distribution media **534**, thereby adjustably varying the pressure drop along the length of distribution manifold **400**.

[0064] **Fig. 6** shows a close enclosure in the form of a transition zone **600** coupled at its upstream end to a process **602** having underlying control surface **604** and overlying control surface **606**. The downstream end of transition zone **600** is coupled to process **608** operating

at a pressure **pB**. Gaskets **610** provide a seal at each end of transition zone **600** and permit removal of the overlying or underlying control surfaces for, e.g., cleaning or web threadup. Transition zone **600** has a fixed overlying control surface **611** and a positionable overlying control surface **612** (shown in phantom in its raised position **613**) that may be manually or automatically actuated to provide headspace values of **h2a, h2b** and values in between. Upper distribution manifold **614** may be used to supply conditioned gas stream $\mathbf{M1'_U}$. The underlying side of transition zone **600** has transport roll **616** inside housing **618**, and underlying control surface **620**. Lower distribution manifold **622** may be used to supply conditioned gas stream $\mathbf{M1'_L}$. Transition zone **600** may be helpful in discouraging large gas flows between adjacent connected processes involving a material difference in respective operating pressures. Foe example, in some processes there may be a two-fold or greater, five-fold or greater or even ten-fold or greater pressure difference between processes at either end of the disclosed close enclosure and transition zone.

[0065] **Fig. 7** and **Fig. 8** respectively show a schematic sectional view and a cross sectional view of a close enclosure **700** having overlying control surface **702**, underlying control surface **704** and sides **706** and **708**. Close enclosure **700** has length $\mathbf{l_e}$ and width $\mathbf{w_e}$. Web **14** has width **w**, and is transported through close enclosure **700** at velocity **V**. Gaskets **709** provide a seal at the sides of overlying control surface **702** and permit its height adjustment or removal (e.g., for cleaning or web threadup). Overlying control surface **702** and underlying control surface **704** are spaced apart a distance $\mathbf{h_{e1}}$. Underlying control surface **704** is spaced apart from substrate **14** a distance $\mathbf{h_{e2}}$. These distances may vary in the upstream or downstream directions. Upstream transition zone **710** has underlying and overlying web slot pieces **711** and **712**. These web slot pieces are spaced apart a distance $\mathbf{h_{1a}}$, and have length $\mathbf{l_1}$. Underlying web slot piece **711** is spaced apart from web **14** a distance $\mathbf{h_{1b}}$. An upstream process (not shown in **Fig. 7** or **Fig. 8**) is in direct gaseous communication with transition zone **710** and has pressure $\mathbf{P_A}$. Downstream transition zone **714** has underlying and overlying web slot pieces **716** and **718**. These web slot pieces are spaced apart a distance $\mathbf{h_{2a}}$, and have length $\mathbf{l_2}$. Underlying web slot piece **716** is spaced

apart from web **14** a distance $\mathbf{h_{2b}}$. A downstream process (not shown in **Fig. 7** or **Fig. 8**) is in direct gaseous communication with transition zone **714** and has pressure $\mathbf{P_B}$. When an upstream or downstream process is required to operate at a large pressure differential from an enclosure such as close enclosure **700**, the transition zones between the upstream or downstream process and the close enclosure may utilize additional dilution (or exhaust) streams to decrease the pressure differential between the process and the close enclosure. For example, convection ovens often operate at large negative pressures (-25 Pa is not uncommon), inducing large gas flows.

[0066] Upper and lower manifolds **720** and **722** respectively may provide gas flows into or out of the upstream end of close enclosure **700** (e.g., conditioned gas streams $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$). Upper and lower manifolds **724** and **726** respectively may provide gas flows into or out of the upstream end of close enclosure **700** (e.g., withdrawn gas streams $\mathbf{M4_U}$ and $\mathbf{M4_L}$). The pressures inside the enclosure can be characterized by $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_{13}}$, $\mathbf{P_{23}}$, $\mathbf{P_3}$ and $\mathbf{P_4}$. The ambient air pressure outside close enclosure **700** is given by $\mathbf{P_{atm}}$.

[0067] The disclosed process and apparatus typically will utilize a web handling system to transport a moving substrate of indefinite length through the apparatus. Those skilled in the art will be familiar with suitable material handling systems and devices. Those skilled in the art will also appreciate that a wide variety of substrates may be employed, including, for example, a polymer, woven or non-woven material, fibers, powder, paper, a food product, pharmaceutical product or combinations thereof. The disclosed process and apparatus may also be used, for example to clean or prime a substrate prior to the application of a coating, as described in copending U.S. Patent Application Serial No. (Attorney docket number 55752US018), filed even date herewith and entitled "COATING PROCESS AND APPARATUS", the disclosure of which is incorporated herein by reference.

[0068] In operation, exemplary embodiments of the disclosed apparatus can significantly reduce the particle count in the atmosphere surrounding a moving web. Exemplary embodiments of the disclosed apparatus may also capture at least a portion of a vapor component from a substrate (if present) without substantial dilution and without condensation of the vapor component. The supplied conditioned gas may significantly reduce the

introduction of particulates into portions of the apparatus surrounding the substrate and thus may reduce or prevent product quality problems in the finished product. The relatively low air flow may significantly reduce disturbances to the substrate and thus may further reduce or prevent product quality problems.

Example 1

[0069] A single close enclosure was constructed to illustrate the effect of certain variables. **Fig. 9** shows a schematic side sectional view of a close enclosure **900**. Close enclosure **900** has overlying control surface **902**, underlying control surface **904** and side **906** equipped with sample ports A, B and C for measuring pressure, particle count and oxygen levels within close enclosure **900**. Overlying control surface **902** and underlying control surface **904** are spaced apart a distance $\mathbf{h_{e1}}$. Underlying control surface **904** is spaced apart from substrate **14** a distance $\mathbf{h_{e2}}$. Upstream transition zone **908** has underlying and overlying web slot pieces **910** and **912**. These web slot pieces are spaced apart a distance $\mathbf{h_{1a}}$, and have length $\mathbf{l_1}$. Underlying web slot piece **910** is spaced apart from web **14** a distance $\mathbf{h_{1b}}$. Downstream transition zone **914** has underlying and overlying web slot pieces **916** and **918**. These web slot pieces are spaced apart a distance $\mathbf{h_{2a}}$, and have length $\mathbf{l_2}$. Underlying web slot piece **916** is spaced apart from web **14** a distance $\mathbf{h_{2b}}$. Upper and lower distribution manifolds **920** and **922** respectively supply conditioned gas streams $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ at the upstream end of close enclosure **900**. Web **14** is transported through close enclosure **900** at velocity **V**.

[0070] Downstream process **924** has movable underlying control surface **926**, overlying control surface **928** equipped with ambient gas inlet **930** and vacuum outlet **932**, and underlying and overlying web slot pieces **926** and **928**. These web slot pieces are spaced apart a distance $\mathbf{h_{B1}}$. Underlying web slot piece **926** is spaced apart from web **14** a distance $\mathbf{h_{B2}}$. These web slot pieces have length $\mathbf{l_3}$. Through appropriate regulation of the flows through inlet **930** and outlet **932**, process **924** can simulate a variety of devices.

[0071] For purposes of this example close enclosure **900** was used with an uncoated web and was not connected at either its upstream or downstream ends to another close enclosure. Thus the surrounding room, with a defined ambient pressure of zero, lies upstream from transition zone **908** and downstream from process **924**. The room air temperature was about 20° C.

[0072] **Fig. 10** shows a plan view of overlying control surface **902**. Surface **902** has length $\mathbf{l_e}$ and width $\mathbf{w_e}$, and contains 5 rows of 3 numbered holes each having a 9.78 mm diameter and a 0.75 cm^2 area, with the lowest numbered holes located at the upstream end of control surface **902**. The holes can be used as sample ports for measuring pressure, particle count and oxygen levels at different locations within the enclosure and may also be left open or taped closed to vary the open draft area of close enclosure **900**.

[0073] Particle counts were measured using a MET ONE™ Model 200L-1-115-1 Laser Particle Counter (commercially available from Met One Instruments, Inc.), to determine the number of 0.5 μm or larger particles in a volume of 28.3 liters, at a 28.3 liters/min flow rate. Pressures were measured using a Model MP40D micromanometer (commercially available from Air-Neotronics Ltd.). Oxygen levels were measured using a IST-AIM™ Model 4601 Gas Detector (commercially available from Imaging and Sensing Technology Corporation). Gas velocities were evaluated using a Series 490 Mini Anemometer (commercially available from Kurz Instruments, Inc.).

[0074] Upper and lower distribution manifolds **920** and **922** were connected to a nitrogen supply and the flow rates adjusted using DWYER™ Model RMB-56-SSV flow meters (commercially available from Dwyer Instruments, Inc.). Vacuum outlet **932** was connected to a NORTEC™ Model 7 compressed air driven vacuum pump (commercially available from Nortec Industries, Inc.). The flow rate was adjusted using a pressure regulator and a DWYER Model RMB-106 flow meter (commercially available from Dwyer Instruments, Inc.).

[0075] Close enclosure **900** was adjusted so that $\mathbf{l_e}$ = 156.2 cm, $\mathbf{w_e}$ = 38.1 cm, $\mathbf{h_{e1}}$ = 4.45 cm, $\mathbf{h_{e2}}$ = 0.95 cm, $\mathbf{h_{1a}}$ = 0.46 cm, $\mathbf{h_{1b}}$ = 0.23 cm, $\mathbf{l_1}$ = 7.62 cm, $\mathbf{h_{2a}}$ = 1.27 cm, $\mathbf{h_{2b}}$ = 0.13 cm, $\mathbf{l_2}$ = 3.8 cm, $\mathbf{h_{B1}}$ = 0.46 cm, $\mathbf{h_{B2}}$ = 0.23 cm, $\mathbf{l_3}$ = 2.54 cm and **V** = 0. The enclosure pressure was adjusted by varying the flow rates $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ and the rate of gas

withdrawal at outlet **932**, using sample port B (see **Fig. 9**) to monitor pressure. Hole 11 (see **Fig. 10**) was used to monitor particle count and sample port C (see **Fig. 9**) was used to monitor the oxygen level. Inlet **930**, the remaining holes in control surface **902** and sample port A were taped closed, thereby providing a minimal open draft area in close enclosure **900**. The results are shown in **Fig. 11** (which uses a logarithmic particle count scale) and **Fig. 12** (which uses a linear oxygen concentration scale), and demonstrate that for a stationary web, material particle count reductions were obtained, at, e.g., pressures greater than or equal to about -0.5 Pa. At positive enclosure pressures, the particle counts were at or below the instrument detection threshold. The curves for particle count and oxygen level were very similar to one another.

Example 2

[0076] Example 1 was repeated using an 18 m/minute web velocity **V**. The particle count results are shown in **Fig. 13** (which uses a logarithmic particle count scale). **Fig. 13** demonstrates that for a moving web, material particle count reductions were obtained, at, e.g., pressures greater than -0.5 Pa.

Example 3

[0077] Using the method of Example 1, a – 0.5 Pa enclosure pressure was obtained in close enclosure **900** by adjusting the flow rates $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ to 24 liters/min and by adjusting the rate of gas withdrawal at outlet **932** to 94 liters/min. In a separate run, a +0.5 Pa enclosure pressure was obtained by adjusting the flow rates $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ to 122 liters/min and by adjusting the rate of gas withdrawal at outlet **932** to 94 liters/min. The respective particle counts were 107,889 at -0.5 Pa, and only 1 at +0.5 Pa. For each run the enclosure pressure above the substrate was measured at several points along the length of close enclosure **900** using holes 2, 5, 8, 11 and 14 (see **Fig. 10**). As shown in **Fig. 14**, the enclosure pressure above the substrate was very steady for each run and did not measurably vary along the length of close enclosure **900**. Similar measurements were made below the web using ports A, B and C. No variation in pressure was observed in those measurements either.

[0078] In a comparison run, pressure measurements were made at varying points inside and outside a TEC™ air flotation oven (manufactured by Thermal Equipment Corp.) equipped with a HEPA filter air supply set to maintain a – 0.5 Pa enclosure pressure. The upper and lower flotation air bar pressures were set to 250 Pa. The make-up air flowed at 51,000 liters/min (equivalent to about 7.5 air changes/minute for a 6800 liter oven capacity, not taking into account equipment inside the oven). The ambient room air particle count was 48,467. The particle count measured approximately 80 centimeters inside the oven was 35,481. The particle counts at several other positions were measured as shown in **Fig. 15**. **Fig. 15** demonstrates that the enclosure pressure varied considerably at the various measuring points, and exhibited further variation due to the action of the oven pressure regulator.

Example 4

[0079] Using the general method of Example 1, the $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ flow rates were set at 122 liters/min and the rate of gas withdrawal at outlet **932** was set at 94 liters/min. The web slot height $\mathbf{h_{1a}}$ was adjusted to values of 0, 0.46, 0.91, 1.27, 2.54 and 3.81 cm. The ambient air particle count was 111,175. **Fig. 16** and **Fig. 17** (which both use linear vertical axis scales) respectively show the pressure and particle count inside the enclosure at various web slot heights. In all instances, a material particle count reduction (compared to the ambient air particle count) was obtained.

Example 5

[0080] Using the general method of Example 1 and a 23 cm wide polyester film substrate moving at 0, 6 or 18 m/min, the $\mathbf{M1'_U}$ and $\mathbf{M1'_L}$ flow rates and the rate of gas withdrawal at outlet **932** were adjusted to obtain varying enclosures pressures. The ambient air particle count was 111,175. The enclosure particle count was measured as a function of web speed and enclosure pressure. The results are shown in **Fig. 18** (which uses a logarithmic particle count scale). **Fig. 18** demonstrates that material particle count reductions were obtained for all measured substrate speeds at, e.g., pressures greater than -0.5 Pa.

[0081] From the above disclosure of the general principles of the disclosed invention and the preceding detailed description, those skilled in this art will readily comprehend the various modifications to which the disclosed invention is susceptible. Therefore, the scope of the invention should be limited only by the following claims and equivalents thereof.